LEVEL II

12

Technical Report: NAVTRAEQUIPCEN IH-333

Performance Measurement and the Navy's Tactical Aircrew Training System (TACTS)

LT Gerald R. Stoffer, Ph.D.
Human Factors Laboratory
Naval Training Equipment Center
Orlando, FL 32813

September 1981

Final Report March - April 1981

NAVAL TRAINING EQUIPMENT CENTER
ORLANDO, FLORIDA 32813

Technical Report: NAVTRAEQUIPCEN IH-333

PERFORMANCE MEASUREMENT AND THE NAVY'S TACTICAL AIRCREW TRAINING SYSTEM (TACTS)

LT GERALD R. STOFFER, Ph.D.
Human Factors Laboratory

Approved:

WILLIAM. P. LANE
Head, Human Factors Laboratory

WILLIAM P. LANE
Acting Director, Research Department

NAVAL TRAINING EQUIPMENT CENTER

ORLANDO, FLORIDA 32813

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NAVTRAEQUIPCEN IH-333	2. GOVT ACCESSION NO.: AD-A110 519
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): PERFORMANCE MEASUREMENT AND THE NAVY'S TACTICAL AIRCREW TRAINING SYSTEM (TACTS)	5. TYPE OF REPORT & PERIOD COVERED: FINAL REPORT - March-April 1981
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): LT Gerald R. Stoffer, Ph.D	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Human Factors Laboratory, Naval Training Equipment Center, Orlando, FL 32803	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62757N, 63701N Task 0713
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: September 1981
	13. NUMBER OF PAGES: 29
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This report was previously published in the Proceedings of the First Symposium on Aviation Psychology, Columbus, OH, 21-22 April 1981.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Performance Measurement
Performance Measurement System
Tactical Aircrew Training System (TACTS)
Air Combat Maneuvering (ACM)
Air Combat Training
Human Factors
Air-to-Air Combat

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The development and use of the Tactical Aircrew Training System (TACTS) as a means for training advanced air combat skills are described. Pilot performance measurement capabilities of the TACTS are reviewed in terms of their value for pilot selection, aircrew training, assessment, and simulator design. Several approaches and methods used to conceptualize and measure air combat maneuvering (ACM) performance are presented. Limitations in existing TACTS performance measurement capabilities are illustrated in terms of several psychometric, training, and TACTS operational user feasibility requirements for a system of

performance measurement. It is concluded that while the existing TACTS represents a highly advanced aviation engineering technology that can provide extremely valuable training, that same technology has largely ignored the functional requirements for a system of human performance measurement. Improvements in the TACTS performance measurement capabilities will improve its training value even further.

PREFACE

The present report was written in response to an air combat training Fleet Project Team (FPT) requirement that a performance measurement system (PMS) for the Navy Tactical Aircrew Training System (TACTS) be developed. It provides a context for the problem and value of performance measurement as well as a set of specific functional requirements for a PMS for air-to-air combat training. In addition, the report provides systematic documentation for the conclusion that, with the development of the extremely impressive TACTS instrumentation technology, there was no parallel development to provide a system of human performance measurement to support that capability. It is thought that development of a PMS, which meets the requirements presented here, will greatly assist in more fully accomplishing the original operational training requirements which led to development of the TACTS facility.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

In the 1950 Korean conflict, American F-86 Sabre jet aircraft destroyed equally capable Soviet MIG-15 aircraft at a rate of 10 MIG's for every Sabre lost (Futrell, 1961). In view of these results, the USAF and USN were surprised at the relatively poor exchange ratios of approximately 2:1 advantage over the North Vietnamese Air Force during the first half of the Vietnam conflict (DeLeon, 1977; Editors, AFJI, 1974). In 1969, the Navy released the results of a study directed by Captain Frank Ault to explain the unexpected poor air combat maneuvering (ACM) performance of U.S. pilots in Southeast Asia. The "Ault Committee Report" (1969) identified deficiencies in air combat training as a primary factor. In particular, many pilots were reported to have fired their weapons (i.e., missiles) outside of tactical launch envelope boundaries. Failure to recognize and fire within an acceptable geometric cone surrounding a target aircraft greatly reduces the probability of kill. Because the Vietnam Air War was the first time that U.S. pilots used missiles as their primary air-launched weapon to destroy enemy aircraft in flight (Craven, 1980), inadequate training in missile envelope recognition was especially apparent.

In response to the Ault Report, the Navy developed a major requirement that a designated airspace (range) and ground support be designed and implemented to provide training in air combat skills. The specific range requirements were: (1) accurate real time weapon envelope recognition training during ACM; (2) accurate recording of training events for debriefing, and (3) safety and economy of ACM training (Air Test and Evaluation, VX-4, reported in Applied Physics Laboratory, 1975). The range, originally called the Air Combat Maneuvering Range (ACMR), is today known as the Tactical Aircrew Training System (TACTS). The general system, functional description, and operating guidelines for TACTS are described in detail elsewhere (User's Guide, 1978).

SECTION II

PURPOSE

Two major training technologies exist to provide Navy air-to-air combat training. The first, TACTS, is the context for the present paper. Following a brief description of the TACTS operational and training capabilities, the remaining sections of the paper will focus on: (1) a description of ACM performance; (2) an analysis of the human performance measurement (PM) capabilities and limitations of TACTS; (3) an assessment of the value of TACTS performance measures for a variety of human factors applications; (4) an identification of different approaches used to conceptualize and measure ACM performance; and (5) development of a set of specific functional requirements for a system of performance measurement.

The major purpose of this report is to indicate the current limitations in Navy TACTS performance measurement relative to an ideal set of functional requirements for a performance measurement system (PMS). The major thesis developed herein is that while the TACTS original design included performance measures, there was no specific design for a system of measurement. It is felt that development of a PMS, which meets the requirements presented here, will greatly assist in more fully accomplishing the original operational training requirements which led to development of the TACTS facility.

The second major training technology, air combat maneuvering simulators (ACMSs), are somewhat more recent innovations. Two classes of simulators are used for Navy ACM training: (1) Weapon System Trainer, Device 2F112, located at NAS Miramar, CA and NAS Oceana, VA; and (2) Air Combat Maneuvering Simulator, Device 2E6, located at Oceana.[1] The ACMSs will not be discussed specifically below, except as an alternative approach to TACTS ACM performance measurement.

[1]A new device, Air Combat Tactics Trainer, 2E7, is scheduled to be ready for training at NAS Lemoore, CA in late 1982, and a second unit for NAS Cecil Field, FL in mid-1983. Youngling et al. (1977) provide a description and evaluation of the several ACMSs used by the Air Force and NASA.

SECTION III

DESCRIPTION OF TACTS CAPABILITIES

EXISTING TACTS OPERATIONAL CAPABILITIES

TACTS is an advanced air combat training system developed to improve aircrew proficiency. In a designated airspace, controlled but realistic ACM missions are flown against U.S. "play to kill" aircraft adversaries that mimic the looks and tactics of Soviets MIGs. With special airborne instrumentation pods, all significant flight parameters, weapon events, and mission data of multiple aircraft are transmitted to ground stations where they are displayed in real time to the range training officer and recorded for replay during post mission debriefing. Tracks of the symbolized aircraft are presented on a three-dimensional (3-D) Cathode Ray Tube (CRT) display. The system also maximizes safety of training. If an aircraft violates any preprogrammed safety parameter, the pre-designated symbol for that aircraft begins flashing on the display screen. The ground instructor can then warn the pilot. Figure 1 portrays the four subsystems comprising TACTS.

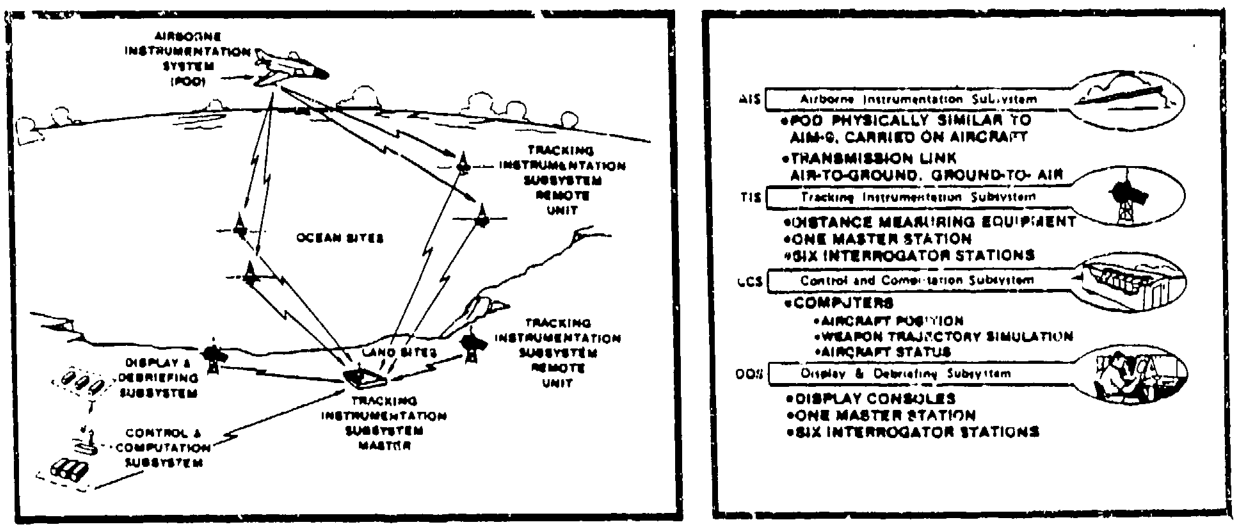

Figure 1. Description of the Four Subsystems of the Tactical Air Combat Training System (TACTS). Description is from the East Coast TACTS User's Guide (May 1978)

---

[2]The Air Force participated in the evaluation of the first Navy range and established a subsequent requirement for an Air Force range called the Air Combat Maneuvering Instrumentation (ACMI). The first ACMI became operational in July 1976 at Nellis AFB, NV, as a technologically updated version of the TACTS.

The first TACTS became operational in December 1973 at MCAS Yuma, AZ[2]. Ground stations for monitoring and debriefing ACM in the Yuma range are available at both Yuma and NAS Miramar. On the east coast, an over-water range became operational in 1976 off Cape Hatteras, NC. Ground training facilities are available at both NAS Oceana, and MCAS, Cherry Point, NC.

EXISTING TACTS TRAINING CAPABILITIES

The TACTS training capabilities provide: (1) highly realistic conditions approximating actual combat; (2) management, and direct control of training by ground-based instructors who can quickly vector participating aircraft into positions to set up for each engagement; (3) several missile envelope recognition training modes, varying progressively in difficulty; (4) immediate knowledge of results of simulated weapon release outcomes; (5) "nondebatable" (i.e., objective) magnetic tape record of certain actions in the aircraft; and (6) recorded flight and weapon action data for performance debriefing and hardcopy feedback.

EMERGING TACTS TRAINING CAPABILITIES

The name change from ACMR to TACTS in 1980 reflects the broadening of anticipated training system capabilities beyond air combat maneuvering to a variety of aircrew combat tasks. Emerging capabilities include simulated air-to-ground weapons delivery (e.g., no-drop bomb scoring), electronic warfare (EW) training, and surface-to-air missile (SAM) avoidance training. Initial studies have been completed to investigate the feasibility of adding by FY86 at-sea monitoring and debriefing capabilities aboard aircraft carrier battle groups to the currently available land-based facilities (Crangle, 1980).[3]

---

[3]Current ranges will also be modified as needed for operational test and evaluation (OT&E) research studies such as the Air Combat Evaluation - Air Intercept Missile Evaluation (ACEVAL-AIMVAL) program - a joint Air Force/Navy evaluation of new air intercept missiles and tactics.

SECTION IV

DESCRIPTION OF ACM PERFORMANCE

The basic ACM task appears simple. The pilot attempts to: (1) destroy the enemy; and (2) avoid being destroyed by the enemy. According to John Johnson (1956), Britain's top fighter ace in WWII, pilots just before an ACM mission. . . "fall into two broad categories; those who are going to shoot and those who secretly and desperately know that they will be shot at . . ." He called the first group "hunters" and the second group "hunted."[4] Traditionally, however, the fighter pilot has been identified with the first, aggressive role and to a much lesser extent with the second, survival role. The cultural mystique surrounding the aggressive fighter pilot and the nature of his combat task are described below.

TASK COMPLEXITY

During ACM the modern pilot must visually detect, identify, and track an adversary which can change position in 3-D geometric space at supersonic speeds. Meanwhile, the fighter must also rapidly manipulate his aircraft and weapon controls, monitor instruments and displays, and coordinate his actions over communication channels with other aircrew and/or friendly fighter aircraft. All these dynamic responses must take place within the typically short, 2-3 minutes, of an ACM engagement. In addition to the stringent perceptual-motor skill requirements, decision-making demands are continuous. For example, missile envelope recognition is a critical decision based on a number of factors, including the kind of aircraft adversary, fighter missile type selected, various rules of thumb for envelope determination, etc.

These perceptual-motor and decision-making skills are "enabled" only through the mastery of a third skill-control over emotional responses.[5] The pilot must keep his "cool" under conditions of high gravitational forces, the possibility of a ground or midair crash, and the extremely rapid loss of fuel during intense ACM on the TACTS. During actual combat, the pilot contends with additional stressors, including the likelihood of multiple adversaries with real weapons, communicaton jamming, SAM missiles and enemy "flak" of various kinds. Although 98 percent of pilots surveyed have highly favorable opinions of the instrumented ACM range as a training facility (Youngling

---

[4]Weiss (1966) dichotomized combat pilots into "Hawks" (those that downed enemy aircraft) and "doves" (those that were shot down by enemy aircraft).

[5]A collaborative effort between the Naval Health Research Center/Naval Training Equipment Center (NAVTRAEQUIPCEN) is planned for FY82 to identify training "stress profiles" of pilots during the experience of ACM and to relate these profiles to objective measures of ACM performance.

et al., 1977), there was also consensus that the relative safety of the training environment limited to some degree transfer of training to the life-threatening episodes of combat ACM.

Air-to-air combat between aircraft is especially complex because in-close aircraft maneuvering is required. The classical and modern "dogfight" or "hassle" between a fighter and an adversary target (called a "bogey") takes place because of a requirement for visual identification (VID) of an adversary prior to weapon release. The operational requirement for VID lessens the likelihood of destroying friendly aircraft. However, VID is not necessary for existing missile effectiveness which can extend well beyond visual acquisition range, and beyond the airspace in which visually controlled dogfighting would otherwise occur.[6]

The abbreviation "ACM" is often used as a catch-all expression for the entire air-to-air combat mission which is highlighted by the aircraft maneuvering engagement, (dogfight). The entire mission includes several kinds of performance skills, including radar procedures, VID intercept procedures, tactics, ACM, weapon system and missile/cannon envelope recognition, and "bugout" (return to base) procedures.

THE "FIGHTER MYSTIQUE"

Until recently, attempts to quantify the highly complex ACM task and to reduce it to elemental sequences of subskills were scarce. The ACM performance measurement (ACMPM) methods described below are all recent products of the last decade. Part of the historical reluctance to develop ACMPM systems can be attributed to what might be called the "fighter mystique" (Eddowes, 1981). There appears to be a general sentiment in the populace that fighter pilots have the "right stuff" (Wolfe, 1980). It is also generally acknowledged that the ingredients for the right stuff are complex and unknown. Even if the ingredients were known, they could not be quantified. Finally, the argument continues, even if they could be quantified, so few people would have the right stuff that measurement would be impractical.

Studies of combat reviewed by Youngling et al. (1977) support the general view that only a few fighter pilots have the right ingredients for combat success. For example, only five percent of the 5,000 fighter pilots who flew against the Germans in WWII during 1943-1945 accounted for 40 percent of the kills recorded by the Eighth Air Force during that period. Even more impressive were the German fighters whose ten best chalked up 2,568 kills among them (Weiss, 1966).

---

[6]Certain navy combat experienced ACM pilots (e.g., Flynn, 1975) feel that the advent of new missile technology "will not eliminate the need for visual identification of enemy aircraft and hence the inevitable dogfight" (p. 4). An identical view has been expressed by Air Force pilots (Ethell, 1980).

The unfortunate consequence of the fighter mystique attitude present in this culture is that the skill components of the ACM task have not been translated into performance measures which could be used to provide training feedback for the majority of fighter pilots who could profit from such feedback. Data from WWI, WWII and the Korean conflict indicate that less than 15 percent of all fighter pilots had a better than even chance of surviving their first combat experience (Weiss, 1966). Based on data such as these, it has been estimated that, without specialized air-to-air combat training, high attrition rates can be expected in future conflicts (Youngling et al., 1977).

SECTION V

EXISTING TACTS ACM PERFORMANCE MEASUREMENT (ACMPM) CAPABILITIES AND LIMITATIONS

As described above, TACTS contributes directly to training by providing an ACM performance measurement capability. TACTS records and plays back objective performance data in a variety of graphic and numeric formats. However, the existing TACTS ACMPM has a number of specific limitations for training which will be described below. The full potential of ACMPM has yet to be realized. As evidence of the need for a system of performance measurement on the TACTS, the Navy Fleet Project Team (FPT) for air combat training, recently stated:

> "A performance measurement system (PMS) is required to determine training effectiveness, act as a diagnostic training aid, and evaluate present/future training device capabilities relative to the syllabus. As a basis for PMS, indices must be identified. A standard PMS should be established." (COMTACWINGSLANT naval message, March, 1981.)

LIMITATIONS IN EXISTING ACMPM

The limitations indicated below confirm the conclusions of the FPT and provide a foundation for the development of a set of requirements for an ACMPMS in support of the fleet.

DATA FLOODING. The performance measures available during ACM and for the ACM debrief are so "rich" that some users have described the scheme as "data flooding". The instructor is genuinely overloaded with such an array of information.

LACK OF SPECIFIC TRAINING OBJECTIVES. Data flooding is a natural consequence of inadequate specification of behavioral objectives. When it is uncertain as to what is being trained, the simple (and often more costly) solution is to measure everything.

LACK OF TREND DATA. A major limitation of the TACTS is that performance data are not accumulated over engagements to identify aircrew trends (Ciavarelli, Williams, & Stoffer, 1981). Trend data are necessary to identify and to diagnose consistent patterns of performance as a baseline for corrective action.

CERTAIN IMPORTANT VARIABLES UNMEASURED. A second consequence of inadequate specification of training objectives is that an important performance variable may go unmeasured. One such variable, time in envelope, is not available under the present TACTS PM. This omission is interesting since envelope recognition skill training was one of the three original requirements leading

to development of TACTS.[7] A second variable, energy management, has only recently been available as a debriefing aid at NAS Miramar. An energy management display (EMD) measures the maneuvering capability of the aircraft by integrating energy maneuverability data available from the TACTS. The ability to maximize maneuvering capability is a major determinant of the outcome of air combat (Deberg, 1977; Pruitt, Moroney, & Lau, 1980).

INADEQUATE DEBRIEF DATA FORMATTING. Much of the performance data available during the debrief is in numeric form which is difficult to visually process and retain. The operational acceptance of the EMD is based in large part on the fact that it is a pictorial display of the energy maneuvering envelope of an aircraft and of its opponent during an ACM engagement. The EMD was developed as a debriefing tool with considerable input from TACTS pilots. Similarly, the complexity of missile envelopes would be more easily understood if represented by graphic than numeric formats. An ongoing project, directed by the Human Factors Laboratory (HFL) at the Naval Training Equipment Center, has focused on the development of methods to standardize the entire debrief feedback in terms of display tables and graphs that are recommended by TACTS users (Ciavarelli, Pettigrew, & Brictson, 1981). Methods for missile envelope representation, and simultaneous representation of associated missile shots, are now available.

LACK OF QUALITY CONTROL OVER RAW PERFORMANCE DATA. Two major emerging systems to provide performance measurement for TACTS will be described in a subsequent section. Both of these efforts, as well as a more recent effort with a similar goal (McGuinness et al., 1980), have had to implement considerable quality control over the performance data prior to data analysis and interpretation. McGuinness et al. have described in some detail a number of limitations in TACTS hardware and operational procedures which consequently require "filtering" of TACTS output data.

---

[7]Even if a time in envelope indication were immediately available, it would probably be necessary to reconstruct or qualify the variable (i.e., on the basis of a rate measure).

SECTION VI

VALUE OF TACTS AS A SOURCE OF PERFORMANCE CRITERIA

The objective performance data available from TACTS are sources of valuable criteria for several purposes, including training.

SELECTION

One of the original (1975) research interests in the TACTS ACMPM was to identify, define and validate behavioral criterion variables for use by the Naval Aerospace Medical Research Laboratory (Brictson, Ciavarelli & Jones, 1977; Brictson et al., 1978). The Vision Research Laboratory, in particular, was interested in developing realistic criteria for validation of certain visual variables used to select naval aviators. There appeared to be an obvious mismatch between current selection variables which emphasize static, high contrast, central vision acuity and the dynamic, low contrast, peripheral vision characteristic of ACM - a major mission of the navy fighter pilot community. In a study using TACTS data, e.g., it was found that the average visual target acquisition ("tally-ho") range was considerably shorter than expectation based on laboratory data on human visual capability (Hutchins, 1978). These laboratory data are the basis for the visual selection tests currently in use by the Navy. Youngling et al. (1977) have systematically reviewed and recommended ACM ranges as intermediate test beds for combat effectiveness predicted by various selection factors.

TRAINING

Performance data are essential to the training process. Measures of ACM subtask skills allow the instructor to monitor the progress of training, as well as to provide diagnostic feedback regarding problem areas. Both norm-referenced and criterion-referenced standards of aircrew proficiency can be established. These behavioral criteria and associated standards inform the instructor and student as to what is to be trained and to what level. Training effectiveness evaluations (TEEs) are then possible.

ASSESSMENT

Assessment of operational ACM readiness, tactics, equipment, safety, and cost-effectiveness of the range, is possible only with the availability of TACTS performance data.

READINESS ASSESSMENT. Once combat becomes necessary, the outcome rests on the quality of the previous aviator selection process and training in ACM. A third factor is placement or deployment of aircrew and squadrons on missions that are suited to their level of operational readiness. Readiness assessment is not concerned with changing the level of ACM proficiency through training; it simply attempts to describe existing squadron and individual differences among fleet fighters.

TACTICS ASSESSMENT. Performance data taken during TACTS engagements can update ACM tactics. The Naval Fighter Weapons School (NAVFITWEPSCOL), called "Topgun," is responsible for teaching advanced ACM tactics. Lessons learned from tactics assessment on the TACTS have already begun to update Topgun tactical guidance, including those that concern throttle control during ACM and various "rules of thumb" for recognizing missile launch envelopes.

EQUIPMENT ASSESSMENT. The technology of TACTS is changing rapidly with the development and introduction of new aircraft (i.e., the F/A-18), new air intercept missiles (i.e., all aspects capable), new performance aids incorporated in Heads-Up-Display (HUD) to improve missile envelope recognition (Lutter, 1979), new EMD performance aids developed to maximize the maneuvering capability of the fighter aircraft (Pruitt et al., 1980), etc. Performance criteria will serve to evaluate whether the use of modified capabilities and performance aids translates into improved performance on TACTS.

SAFETY ASSESSMENT. Similar to commercial airline recording of flight data and human performance for subsequent analysis for safety factors, TACTS allows both on-line and off-line capability for safety assessments leading to corrective and/or preventive feedback.

COST-EFFECTIVENESS ASSESSMENT. The use of simulated weapons and targets has greatly decreased the cost (and increased the safety) of ACM practice. The producer of the instrumented air combat ranges for both the Navy and the Air Force estimates that the TACTS/ACMI reduces air combat training costs by more than $100 million annually (Cubic Corporation, 1978). According to Bill Dollard (1980), the TACTS manager at Miramar, the first system developed for Miramar cost approximately $25 million in R&D and installation of the system in an operational mode. The system costs less than $1,000 an hour to operate. However, these savings must be assessed in terms of performance effectiveness measures on the TACTS.

SIMULATION DESIGN

One of the most important values of PM is its role in training device design. Future Navy air combat training simulators will be designed with the benefit of TACTS performance data that has validated certain ACM simulator training capabilities and not others. In particular, the simulator's PMS can be designed to overlap that available on the TACTS. Common performance measures between ACM trainers and TACTS would provide an ideal foundation for effectiveness evaluations of simulators (see McGuinness et al., 1980).

SECTION VII

MAJOR APPROACHES TO ACM PERFORMANCE MEASUREMENT (ACMPM)

The literature on ACMPM can be organized on the basis of common approaches to the problem of measurement.

SYSTEMS VIEW VS. COMPONENT VIEW

Most researchers in this field have taken a systems view of ACMPM. Thus, human performance and its measurement is viewed as only one component dependent on other elements in an ACM training system. The system includes such elements as aircrew, instructors, aircraft, weapons, and operating conditions, all of which impact performance output.

MULTIVARIATE VS. UNIVARIATE ANALYSES

Most researchers have recognized the complexity of ACM success and have adopted various statistical techniques to deal with this complexity. Not surprisingly, multivariate methods such as multiple regression (Coward et al., 1979), factor analysis (Doberg, 1977), and discriminant function analysis (Kelly et al., 1979), have been applied primarily with ACM simulators rather than with the TACTS. In contrast to TACTS, these simulators allow sufficient pilot sample size and repeated measures on selected variables to allow the use of multivariate statistical approaches to the development of ACMPM.

The Readiness Estimation System (RES), described below, provides a performance index of ACM based on complex mathematical models that incorporate a number of airplane and inter-airplane parameters typically measured by the TACTS.

It should be noted that operational users (Seminar, 1980) of TACTS are generally opposed to a simple, univariate characterization of performance. Their legitimate fear is that ACM training would be geared to achievement of that particular performance metric to the exclusion of others critical for ACM proficiency. In addition, there appears to be a desire to avoid labeling the performance of any particular pilot based on one measure that might have adverse effects on his competitive spirit. Resolution of the apparent conflict between research development of single metrics and the concerns identified above will be found, in part, by development of a composite measure of ACM success, dependent on multiple tasks, with each task weighted according to its relative contribution to overall ACM success. This composite measure, under development by the NAVTRAEQUIPCEN Human Factors Laboratory, will allow both subtask and composite ACM task performance feedback, to supplement the traditional measure of ACM success in terms of fighter/adversary kill exchange ratios.

"BUILDING BLOCKS" VS. "TOP-DOWN" VIEW OF ACM SUCCESS

Some (e.g., Ciavarelli, Williams, & Krasovec, 1980) have chosen a hierarchical or "building blocks" system approach to development of a PMS by

first focusing on specific ACM tasks that are evaluated at various layers in the performance hierarchy for criticality to ACM success. Others use a "top-down" approach by focusing on ultimate or penultimate performance measures of ACM success and then proceeding to subtask analysis. For example, McGuinness et al. (1980) have sharply criticized approaches based strictly on subtask analysis. At some level, however, agreement between these two approaches will eventually be reached.

Performance variables at different levels in the measurement hierarchy are useful for different purposes. For example, task and subtask approaches provide sufficient detail for individual pilot diagnostic feedback. At this level it is possible to find out what specific skills superior fighter pilots possess so that these skills can be trained in new pilots. Approaches that focus on system output level such as exchange ratios provide valuable information for overall squadron readiness assessment. The RES, e.g., provides overall ranking of aircrew and squadrons on the basis of overall maneuvering scores, but does not allow for individual diagnostic information to explain differences in maneuvering proficiency. At the system level are output variables that are used to assess the relative contribution of various subtasks and to construct a composite measure of ACM success referred to above. Thus, not only do performance measures at various levels in the hierarchy serve useful purposes by themselves but they also complement each other in a complete system of performance measurement.

DYNAMIC VS. STATIC REPRESENTATIONS OF PERFORMANCE

The original TACTS provides qualitative feedback through dynamic replay of the entire engagement. Some more recent PM schemes (i.e., the RES) provide performance feedback regarding the dynamic interplay between opposing aircraft. The RES provides a time-history, quantitative index score of maneuvering performance based on continuous measurement throughout the engagement.

Other approaches conceptualize maneuvering as one rather discrete step in a total ACM mission sequence preceded by radar procedures and lookout procedures, and followed by envelope recognition procedures (Ciavarelli et al., 1981). Obviously, the dynamic properties within each of these discrete "steps" could be elaborated into a PM metric. For training diagnostic purposes, however, there is considerable value in providing initial performance feedback in the form of discrete and comprehensible steps involved in the task to be trained. The more complex and less comprehensible performance dynamics associated with each step should be reserved until the pilot has achieved minimal proficiency at those particular steps. In reality, the distinction between dynamic and static representations of performance becomes blurred to the extent that sequential dependencies between discrete events in the ACM mission can be established, as has been demonstrated by Ciavarelli and his associates.

PRESELECTED PILOTS VS. PRESELECTED VARIABLES

Most research in ACMPM falls into one of two approaches. One approach (e.g., Kelly et al., 1979) first preselects pilots high or low in overall ACM proficiency, on the basis of instructor ratings, simulator performance, or past TACTS records. These two groups are then contrasted on the basis of a large number of specific performance measures. Measures that differentiate the two groups are prime candidates for the PM scheme. The second, and more common approach, preselects a limited number of specific variables for possible inclusion into the PM scheme and then tests them for relative reliability and validity across a wide range of pilot proficiency levels.

AIR COMBAT MANEUVERING SIMULATOR (ACMS) VS. TACTS

Ideally, the design of ACM simulators and their associated PM system is preceded by development of a PM system validated on the TACTS range itself. Unfortunately, none of the existing Navy ACMSs has benefitted from a TACTS PMS. Thus, ACM simulators have been recently used not only to develop ACM PMSs for use with the simulators themselves, but also as a major approach for developing a possible PMS for TACTS. Through an iterative process, there will eventually be developed a set of measures common to the ACMS and TACTS.

In addition to the obvious benefits of increased safety and economy in an opertaional training area traditionally characterized by high risk and high cost, ACMSs allow pilots to experience a wide variety of tactical situations and gain more practice with these situations than is currently possible on the TACTS. Thus, with the ACMS, it is feasible to actively control training experience and to achieve repeated measures of performance data - both of which are essential for PMS development and extremely difficult with the TACTS. The only systematic attempt to develop an ACMS PMS with the Navy is just beginning, with the 2E6 at Oceana, under the direction of the NAVTRAEQUIPCEN Human Factors Laboratory.[8]

---

[8]There are two other emerging and continuing Air Force ACMS PMSs - one called Tactical Space (TACSPACE) under joint AFHRL/NAVTRAEQUIPCEN sponsorship (Kelly et al., 1979), and one called the Good Stick Index (GSI) developed by Coward et al. (1979).

SECTION VIII

FUNCTIONAL REQUIREMENTS FOR AN ACMPM SYSTEM

In view of the above described limitations of original TACTS PMS, the recent FPT message stating the need to develop a PM system for use with the TACTS, and the tremendous potential value of TACTS performance criteria, it is clear that functional requirements for a PM system should be identified. As indicated previously, a <u>system</u> of ACM measurement is yet to be developed.

The purpose of this section is to identify several psychometric, training, and user feasibility requirements that must be met for a PMS to be developed. These functional requirements will be briefly described using two emerging TACTS ACMPMSs. Both systems use the original TACTS ACMPM as a basis for elaboration. Both emphasize highly automated methods to manage the TACTS outputs. It is not intended to comprehensively compare the two or to recommend either one or the other PMS. If anything, both systems are recommended for further development. They were chosen to illustrate PMS requirements because they are the only systems that: (1) have been under development for several years; (2) meet many of the requirements identified below; (3) have a considerable body of technical documentation available for evaluation; (4) are familiar to operational users on both coasts; and (5) have been accepted or implemented to some degree on both coasts.[9] These two PMSs will be briefly described below.

The Readiness Estimation System (RES) is an automated, off-line and time-based measurement system under development that continuously calculates the relative positional advantage/disadvantage of the fighter aircraft at a specific point in the engagement. It provides useful data for envelope recognition plus tactics and maneuvers. Plotted data provide information related to both time history, and time in envelope which is not available on

---

[9]The Fleet Fighter ACM Readiness Program (FFARP) generates the "Blue Baron" reports that summarize individual squadron performance data taken directly from TACTS output. The FFARP is a relatively structured and concentrated three-week syllabus of ACM sorties on the TACTS. It is conducted annually by an adversary squadron. FFARP exercises, until recently, were limited to east coast TACTS. The FFARP analyses are regarded herein as an incomplete system of PM, primarily because they contain most of the limitations of the original on-line TACTS ACMPM. They do provide valuable hardcopy record of data manually retrieved from the TACTS. However, squadron feedback from FFARP exercises is currently taking in excess of two weeks and the performance results are costly to generate.

the original TACTS. The RES was developed by Simpson (1976) and Simpson and Oberle (1977).[10]

The Performance Assessment and Appraisal System (PAAS) is an automated off-line system under development to provide a systematic ACM performance debrief, including computer graphic formats, multiple-referenced standards of performance, diagnostic analyses of ACM subtask, and squadron performance summaries. It can be described as an information management system. PAAS is presented in more detail by its developers in a separate paper in these proceedings (Ciavarelli, Williams, & Brictson, 1981).

PSYCHOMETRIC REQUIREMENTS

Psychometric requirements are the traditional and necessary ones that establish the statistical soundness of a measurement system. They represent an application of the more general requirements for any measurement system to human performance measurement. Several specific requirements are identified below.

OBJECTIVITY. Objective raw data indicators of performance, routinely available from TACTS, are the foundation for the two emerging TACTS PMSs. Without objectivity, there is no system of measurement because everyone is free to construct his own subjective "system". Since the TACTS can provide objective criteria, long lacking in both selection and training of military aviators, North and Griffin (1977) refer to the possibility of TACTS as an "ultimate" criterion for evaluation of naval aviator selection variables in a highly realistic, advanced training environment. Similarly, since scientists are no longer limited to instructor or peer ratings to assess training, some researchers (Ciavarelli & Brictson, 1978) have referred to the TACTS PM capabilities as the dawning of a "golden age" in operational training PM.

RELIABILITY. Objective measures must be reliable. Reliable performance measures provide the consistency and permanence necessary for system stability. Although there are several methods for measuring reliability, one most appropriate for ACM training is temporal reliability. If, e.g., enemy aircraft visual identification (VID) accuracy is a reliable measure, a particular pilot should be equally proficient (or non-proficient) at the VID task across several recordings of VID performance. Thus, reliability is the basis for the diagnosis of consistent pilot trends in performance. Diagnosis of individual pilot performance allows corrective action of substandard performance through individualized training. Unfortunately, neither the RES nor the PASS have documented the reliability of the measures in their PMS. The major limitation to reliability determinations has been the typically

---

[10] A major modification of the RES, called the Readiness Index Factor (RIF) has been made by operational aircrew members at the Oceana TACTS. The RIF is currently under evaluation by the NAVTRAEQUIPCEN as a performance measurement tool for use in a study examining the transfer of training from an ACM simulator (2E6) to the TACTS.

small number of repeated measures of performance available for specific aircrews using the TACTS.

VALIDITY. System validity exists only if the measurement variables are meaningful. VID performance, e.g., gains its meaning only through its correlation with other variables, regardless of how consistent or reliable VID performance might be. VID correlates with air combat engagement success, both according to tactical doctrine (NFWS) and empirical research tests of actual performance on the TACTS (Brictson et al., 1977; Ciavarelli, Brictson, & Young, 1979). Thus, the VID subtask measure has predictive validity as it can predict ACM success.

Concurrent validity is present when one performance measure correlates with other performance measured concurrently (or nearly concurrently) in time. For example, a fighter pilot is twice as likely to get a VID on the TACTS if he has gotten radar contact than if he has not (Ciavarelli et al., 1980). Confirmation of such sequential probabilities between ACM subtasks is also in agreement with tactical doctrine.

An ACMPMS is not completely valid without content validity, which exists when the performance measures are inclusive or at least representative of the ACM task. Thus, a thorough job analysis of ACM is required to ensure that the performance measures selected represent the kinds of subtask content required for ACM engagements. Although the RES has very little predictive or concurrent validity documentation available, it is strong in content validity because it focuses its measurement system on the maneuvering task (ACM) which is uniformly regarded as the most visible and dramatic content of air-to-air combat.

SENSITIVITY. A measurement subsystem is sensitive to other subsystems of the overall training system. If there is a PMS, it is, by definition of a system, interrelated with other subsystems. A system of ACM performance measures, therefore, will be sensitive to changes in other TACTS subsystems such as aircrew, instructors, weapons. etc. To illustrate, the PAAS measures are highly sensitive to differences in commonly acknowledged aircrew proficiency levels between fleet operational squadrons and the typically more experienced fleet reserve fighter pilot squadrons (e.g., Ciavarelli et al., 1980). Similarly, differences in thrust to weight ratios and wing loadings of different aircraft are routinely reflected in the RES metric.

QUALITY CONTROL. A system of measurement does not admit as input data that does not meet certain quality of raw data requirements. Only through systematic filtering of input does a system maintain its characteristic and recognizable features. Moreover, such quality control is necessary to achieve reliability, validity, and sensitivity of the PMS. Both the PAAS and the RES have quality control procedures for data entry into the PMS.

TRAINING REQUIREMENTS

Training requirements for a PMS are those specifically appropriate for use in training applications. They are met most completely when the above psychometric requirements have been met.

DESCRIPTIVE. A system of measurement should, at minimum, provide a complete description of relevant performance. The RES, e.g., traces continuously the maneuvering skills of the pilot over the course of an engagement.

EVALUATIVE. In order to standardize training, it is necessary to evaluate performance in terms of established standards of performance. Common standards against which individual performance may be gauged are a necessary part of a PMS. At least two kinds of standards are required to fully evaluate ACM performance. Criterion-referenced standards are based on an absolute reference point that represents the criterion performance to be reached by aircrew members. For example, tactical doctrine prescribes missile envelope boundaries outside of which missile launches would be classified as errors. It is possible to compare directly tactical envelopes (the criterion) with actual shots (placements) taken in TACTS to verify that shots were within the prescribed boundaries.

Since all pilots do not always meet criterion on all ACM subtasks, it becomes necessary to describe the variability of performance on different subtasks. Norm-referenced standards describe the average or normative performance, regardless of preestablished criterion levels. Normative performance is described essentially by using group averages with a second statistic representing variability of individual performance around that average. For example, tactical missile envelope boundaries can be compared to normative envelopes based on empirical data taken from the TACTS. One practical use of normative standards is to develop criterion standards from them. DeLeon (1977), e.g., suggests that training to gain incremental increases in air-to-air combat skills above the average skill levels is more reasonable than trying to train everyone to be an ace. Both kinds of standards have been developed for some subtasks (cf., Ciavarelli et al., 1980). Ideally, users will soon be able, via automated PMS features, to select and create their own performance norms for various TACTS operating conditions.

DIAGNOSTIC. A PMS provides the opportunity for self-correction on the basis of performance feedback. The system provides enough detail in its diagnosis of tasks or subtasks that the individual can recognize those specific behaviors that are not currently meeting established standards. The RES was not constructed to be diagnostic of individual aircrew tasks but to represent the overall level of aircrew readiness. The diagnostic capability for PAAS is just now beginning to emerge.

REMEDIAL. A PMS not only informs an individual of his skills (i.e., diagnosis), and the level of skill achievement (i.e., evaluation), it also identifies specific corrective actions in the event that remedial action is necessary. Neither PASS nor RES provides remedial training currently.

TIMELY. To maximize the self-corrective feature of a PMS, feedback should be as rapid and as continuous as possible. Because the PASS and RES are off-line systems that cannot operate while TACTS training is in progress, neither PMS provides immediate ACM feedback after an ACM engagement. However, both systems can provide extensive feedback within 24-48 hours.

USER FEASIBILITY REQUIREMENTS

User feasibility requirements are essential to a PMS because if they are not met the "system" will not be used. These requirements basically deal with the operational user's cost, ease, and overall acceptability of operating the PMS. They are even more specific than the training requirements illustrated above because they apply to ACM training in particular and the feasibility issues associated with that specific application.

AFFORDABLE. At this point, both the PAAS, and particularly the RES, require an analyst to process and interpret the performance feedback from the PMS Before either PMS gains long-lasting use, it will be necessary to minimize those costs which support the system.

ADAPTABLE. Changes induced by system growth, and changes in user needs, including changes in training, must not disrupt the basic operation of the PMS. Design modularity is essential. Thus, it should not be essential to continue measuring out-of-date variables in order to add a new and necessary measurement variable. Likewise, it should not be essential to eliminate still useful variables in order to drop an old and now unnecessary variable. The PASS, and to a lesser extent, the RES, are modularized so that they will not lose their system status due to system growth.

AUTOMATED. Much of the data currently available to users of the TACTS are only available with a great deal of manual extraction efforts. Since instructor and student workload can prevent use of otherwise valuable performance feedback, both the RES and PASS are automated.

MANAGEABLE. Designers of the PMS should reduce the number of feedback variables to those required for meeting behavioral training objectives. The data flooding referred to earlier is evidence of the confusion that a PM system serves to reduce. The PASS and RES share a significant advantage in this respect.

ACCESSIBLE. For performance data to be used, they must be easily accessible by the user subsystem that interacts with the PMS subsystem. An ideal PMS makes it rather simple for users to both enter and retrieve performance data. The PAAS, in contrast to the RES, was designed especially with accessibility in mind, by incorporating a number of "user friendly" computer features.

NON-INTERFERENCE WITH TRAINING. Both PMSs are currently off-line because their on line operation would require dedicated TACTS computer time which would decrease the amount of already scarce ACM training time. Although the ultimate goal is to gain on-line PMS capabilities, off-line processing is the only currently feasible alternative.

ACCEPTABLE. Acceptability is an umbrella term for all user requirements that determine whether TACTS users will, in fact, be motivated to use the PMS. For example, the RES, a PMS with a great deal of techni merit, has undergone major modifications at Oceana, partly because it was not easily understood or used. Without user acceptability, even a well-validated and low cost PMS has

no value. Thus, certain ACMPMS features that have more to do with motivational than instructional capabilities per se are required for acceptability. Motivational factors that impact system utilization include user choice of alternative graphic display formatting of performance feedback, possibility for instructor override and flexible use of automated PMS, administrative record keeping assistance to the instructor by the PMS, privacy coding of performance results, etc.

SECTION IX

CONCLUSIONS: TACTS TECHNOLOGY AND HUMAN PERFORMANCE MEASUREMENT

Without question, the TACTS is an impressive application of state-of-the-art technology in airborne instrumentation and tracking, computer-generated simulation of weapon launch outcomes, video tape playback of voice transmissions and graphic portrayal of flight history data. Equally impressive, however, is the conclusion that the TACTS was developed and is currently operated without the benefit of a system of performance measurement. This conclusion is based on several observations: (1) identification of several limitations in the TACTS capabilities for training; (2) a recent (March 1981) naval message from the FPT for air combat training that an ACMPMS was needed; (3) recent attempts by operational users of the east coast TACTS facility to develop their own PMS; and (4) a mismatch between the original TACTS PM scheme and a set of psychometric, training, and user feasibility requirements for a PM system (PMS).

In terms of the three original requirements leading to development of TACTS, the third requirement, for safety and economy of training, has been achieved. Fulfillment of the second requirement, for a performance debrief capability, depended in large part on the development of a PMS and, therefore, has been only partially achieved. The first requirement, for missile envelope recognition training, is difficult to evaluate because there is not one envelope, but multiple envelopes to be learned for different missiles and aircraft capabilities. In addition, there is no completely uniform agreement as to the "proper" firing envelope for a specific missile. Thus, it is not surprising that several systematic samples of launch data obtained on the TACTS indicated that even experienced pilots often fire outside of prescribed doctrinal missile envelope limits (Ciavarelli, Narsete & Brictson, 1981).[11] Such variability in performance is in part due to the lack of a PMS for standardization of envelope recognition training.[12]

---

[11]A major advantage of TACTS is that it allows such systematic evaluations of envelope recognition skills.

[12]A second major reason is that TACTS users do not generally use the five available envelope recognition training modes which vary progressively in level of difficulty and amount of feedback provided. The strong preference is to use mode five which is the most realistic and challenging one. A third significant reason is that the TACTS provides very little envelope recognition practice for any particular aircrew. Access to the range is highly competitive. During TACTS, the engagements are usually no more than several for each aircrew and engagements typically last less than a few minutes. Users (e.g., Carter, 1979) point out that the recognition skill is "achieved only through repetitive exposure to possible firing situations (p. 68)". An analytical effort prior to TACTS development to identify recognition training capabilities would almost certainly have concluded that simulator training would be needed to supplement practice on the TACTS.

The theme for the 1981 Symposium on Aviation Psychology asked, "Is advancing technology ignoring human performance in aviation systems?" It would appear that with the development of the TACTS instrumentation technology, there was no parallel development to provide a PMS to support that capability. This apparent "oversight" is a little easier to understand when one considers the almost mind-boggling complexity of the ACM task and the fighter mystique which is the cultural heritage associated with ACM. In addition, during production of the original TACTS, there was not available a well-developed PMS that could have been further developed.

It was suggested that there are several viable approaches to the measurement of TACTS performance. Two promising and emerging systems of ACMPM were described and used to illustrate a set of functional requirements for a PMS. Fulfillment of these requirements will provide valuable performance criteria for a number of different purposes, including maximization of the training capabilities of the TACTS, and will allow the "golden age" of operational performance measurement to mature.

REFERENCES

Applied Physics Laboratory, Johns Hopkins University. Final report on ACMR evaluation: Data collection instrumentation operational suitability, Volume II, Contract 600084. Flight Systems Inc., May 1975.

Ault Committee Report. Report of the air-to-air missile systems capability review. COMNAVAIRSYSCOM, January 1969.

Brictson, C.A., Ciavarelli, A.P., & Jones, T.N. Development of aircrew performance measures for the air combat maneuvering range (ACMR) (U). Naval Aerospace Medical Research Laboratory, Technical Report L53001, June 1977. (CONFIDENTIAL)

Brictson, C.A., Ciavarelli, A.P., Pettigrew, K.W., & Young, P.A. Performance assessment methods and criteria for the air combat maneuvering range (ACMR): Missile envelope recognition (U). Naval Aerospace Medical Research Laboratory, Special report 78-4, July 1978. (CONFIDENTIAL)

Carter, L., II. Fighter crews: You fight the way you practice. Proceedings of the Naval Institute, 1979, April, 65-69.

Ciavarelli, A.P., & Brictson, C.A. Air combat maneuvering range: Has operational performance measurement entered a golden age? Human Factors Society, Detroit, MI, October 1978.

Ciavarelli, A.P., Brictson, C.A., & Young, P.A. Development and application of performance criteria and aircrew assessment methods for the air combat maneuvering range (ACMR) (U). Naval Aerospace Medical Research Laboratory, Special Report 79-5, September 1979. (CONFIDENTIAL)

Ciavarelli, A.P., Narsete, E.M., & Brictson, C.A. A problem definition study of U.S. air-to-air missile envelope recognition training. Naval Training Equipment Center, Technical Report 78-C-0136-2, in press. (CONFIDENTIAL)

Ciavarelli, A.P., Pettigrew, K.W., & Brictson, C.A. Development of a computer based air combat maneuvering range debrief system. Naval Training Equipment Center, Technical Report 78-C-0136-1, September 1981.

Ciavarelli, A.P., Williams, A.M. & Brictson, C.A. Development and application of air combat performance assessment methods. Symposium on Aviation Psychology, Columbus, OH, April 1981.

Ciavarelli, A.P., Williams, A.M., & Krasovec, K. Operational performance measures for air combat: Development and application. Human Factors Society, Los Angeles, CA, October 1980.

REFERENCES (cont'd)

Ciavarelli, A.P., Williams, A.M., & Stoffer, G.R. Training improvements for the tactical aircrew training system (TACTS): Project summary report. Naval Training Equipment Center, Technical Report 78-C-0136-3, September 1981.

COMTACWINGSLANT, Oceana, VA. Naval Message 232030Z March 1981, Subj: Report of Meeting of Fleet Project Team (FPT) for Air combat Training. (U)

Coward, R.E., Moore, S.B., Madison, W.G., Sepp, G.D., & Stracener, J.T. Air combat training: Good stick index validation. Air Force Human Resources Laboratory, AFHRL-TR-79-15, June 1979.

Crangle, R.H. TACTS program review, Naval Air Systems Command (AIR-06EA). Proceedings of the Seventh TACTS/ACMI User Seminar, San Diego, CA, May 1980.

Craven, P.R. The TACTS/ACMI Microcosm. Sea Power, 1980, December, 41-42.

Cubic Corporation. Cubic corporation capabilities, October 1978.

DeBerg, O.H. A scoring algorithm for assessing air-to-air combat performance, phase I: A factor analysis. Air Command and Staff College, Air University, Report 0590-77, May 1977.

DeLeon, P. The peacetime evaluation of the pilot skill factor in air-to-air combat. The Rand Corporation, R-2070-PR, January 1977.

Dollard, W. Cited by K. Cooper in, Navy uses 'TV game' replays to improve air combat training. San Diego Union, September 14, 1980.

Eddowes, E. Measuring pilot air combat maneuvering performance. Symposium on Aviation Psychology, Columbus, OH, April 1981.

Editors. You fight like you train, and TOPGUN crews train hard. Armed Forces Journal International, 1974, May, Pp. 25-26, 34.

Ethell, J. The modern dogfight. Air Progress, 1980, 42 (June), Pp. 41, 66, 68.

Flynn, S.C., Jr. Flight simulation and the "dogfight". Unpublished manuscript, 1975.

Futrell, R. The United States Air Force in Korea, 1950-1953. New York: Duell, Sloan, & Pearce, 1961.

REFERENCES (cont'd)

Hutchins, C.W., Jr. The relationship between air combat maneuvering range (ACMR) output measures and initial visual acquisition performance. Naval Aerospace Medical Research Laboratory, Special Report 79-1, August 1978.

Johnson, J.E. Wing leader, London: Chatto & Windus, 1956.

Kelly, M.J., Woolridge, L., Hennessy, R.T., Vreuls, D., Barnebey, S.F., Cotton, J.C., & Reed, J.C. Air combat maneuvering performance measurement. Air Force Human Resources Laboratory, Flying Training Division, AFHRL-TR-79-3, September 1979.

Lutter, R.N. Information transfer for improved pilot performance. AGARD Aerospace Medical Panel Specialist Meeting, Lisbon, Portugal, October 1979.

North, R.A., & Griffin, G.E. Aviator selection 1919-1977. Naval Aerospace Medical Research Laboratory, Special Report 77-2, October 1977.

McGuinness, J., Forbes, J.M., & Rhoads, J.E. Applied training effectiveness evaluation methodology. Naval Training Equipment Center, Technical Report 79-C-0016-1, April 1980.

Pruitt, V.R., Moroney, W.F., & Lau, C. Energy maneuverability display for the air combat maneuvering range/tactical training system (ACMR/TACTS). Naval Aerospace Medical Research Laboratory, Special Report 80-4, October 1980.

Seminar, Aircrew Performance and Readiness Evaluation. NAS Oceana, VA, March 1980.

Simpson, W.R. Development of a time invariant figure-of-merit for use in analysis of air combat maneuvering engagements. Naval Air Test Center, TM 76-1 SA, July 1976.

Simpson, W.R. & Oberle, R.A. The numerical analysis of air combat engagements dominated by maneuvering performance. Naval Air Test Center, TM 77-2 SA, June 1977.

User's guide: Air combat maneuvering range (east coast). SRI International, COMNAVAIRSYSCOM No. 78-C-0090, May 1978.

Weiss, H.K. Systems analysis of limited war. Annals of Reliability & Maintainability, 1966, 5.

Wolfe, T. The right stuff. New York: Bantam Books, 1980.

REFERENCES (cont'd)

Youngling, E.W., Levine, S.H., Mocharnuk, J.B., & Weston, L.M. Feasibility study to predict combat effectiveness for selected military roles: Fighter pilot effectiveness. Defense Advanced Research Projects Agency, Report MDC-E-1634, April 1977.

DISTRIBUTION LIST

Commanding Officer
Naval Training Equipment Center
Orlando, FL 32813 (63)

Defense Technical Information Center
Cameron Station
Alexandria, VA 22310 (12)

(All other addresses receive one copy)

OUSDR&E (R&AT)(E&LS)
CDR Paul R. Chatelier
Washington, DC 20301

Chief of Naval Operations
OP-987H
Attn: Dr. R. G. Smith
Washington, DC 20350

Chief of Naval Material
MAT 031M
Washington, DC 20360

Chief of Naval Material
MAT 08D2
CP5, Room 678
Attn: Arnold I. Rubinstein
Washington, DC 20360

Commander
Naval Air Systems Command
AIR 340F
Attn: CDR C. Hutchins
Washington, DC 20361

Commander
Naval Air Systems Command
AIR 413
Washington, DC 20360

Deputy Chief of Naval Operations
(MPT)
Attn: OP-115
Arlington Annex, Room G836
Washington, DC 20370

Dr. Sam Schiflett
Naval Air Test Center
SY 721
Patuxent River, MD 20670

Aerospace Psychology Department
Naval Aero Medical Research Lab
Naval Air Station
Pensacola, FL 32508

Chief of Naval Education and Training
Code N-2
Attn: CAPT Bauchspies
Pensacola, FL 32508

Chief of Naval Technical Training
Code 0161
NAS Memphis (75)
Millington, TN 38054

Chief of Naval Air Training
Attn: Code 3146
NAS
Corpus Christi, TX 78419

Commander
Naval Air Force
US Pacific Fleet (Code 316)
NAS North Island
San Diego, CA 92135

Navy Personnel Research and Development Center
Attn: M. McDowell
Library, Code P201L
San Diego, CA 92152

Dr. Henry M. Halff
Office of Naval Research
Code 458
Arlington, VA 22217

TAWC/TN
Eglin AFB, FL 32542

DISTRIBUTION LIST (cont'd)

Commander
Naval Air Development Center
Attn: Code 6021 (Paul Linton)
Warminster, PA 18974

USAHEL/USAAVNC
Attn: DRXHE-FR (Dr. Hoffman)
P. O. Box 476
Ft. Rucker, AL 36362

Chief
ARI Field Unit
P. O. Box 476
Ft. Rucker, AL 36362

Mr. Harold A. Kottman
ASD/YWE
Wright-Patterson AFB, OH 45433

Chief, Methodology and Standards Staff
Federal Aviation Administration
Academy
Aeronautical Center, AAC-914
P. O. Box 25082
Oklahoma City, OK 73125

Headquarters
Air Training Command, XPTI
Attn: Mr. Goldman
Randolph AFB, TX 78148

AFHRL/MP
Brooks AFB, TX 78235

U.S. Air Force Human Resources Lab
AFHRL-MPM
Manpower Personnel Division
Manpower & Force Management Systems Branch
Brooks AFB, TX 78235

Scientific Technical Information Office
NASA
Washington, DC 20546

Dr. Jesse Orlansky
Institute for Defense Analyses
Science and Technology Division
400 Army-Navy Drive
Arlington, VA 22202

US Air Force Human Resources Lab
TSZ
Brooks AFB, TX 78235

AFHRL/PE
Brooks AFB, TX 78235

US Air Force Human Resources Lab
AFHRL-TT (Dr. Rockway)
Technical Training Division
Lowry AFB, CO 80230

AFHRL/MP
Brooks AFB, TX 78235

Naval Biodynamics Laboratory
Box 29407
New Orleans, LA 70189

Commander, Naval Air Force
U.S. Atlantic Fleet (R. Goodwin)
Norfolk, VA 23511

Commander, Naval Air Force
U.S. Pacific Fleet (J. Bolwerk)
NAS North Island
San Diego, CA 92135

Commander, Tactical Wings, Atlantic
Attn: CAPT Lusk
NAS Oceana
Virginia Beach, VA 23460

DISTRIBUTION LIST (cont'd)

U.S. Air Force Human Resources
Lab
AFHRL-FT
Flying Training Division
Attn: Dr. Edwards
Williams AFB, AZ 85224

Chief of Naval Education and
Training Liaison Office
Human Resource Laboratory
Flying Training Division
Williams AFB, AZ 85224

Mr. R. E. Coward
ASD/YWB
Wright-Patterson AFB
Dayton, OH 45433

American Psychological Assn.
Psyc. Info. Document Control Unit
1200 Seventeenth Street, NW
Washington, DC 20036

The Van Evera Library
Human Resources Research
Organization
300 N Washington Street
Alexandria, VA 22314

PERI-OU
U.S. Army Research Institute for
the Behavioral & Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333

AFHRL Technology Office
Attn: MAJ Duncan L. Dieterly
NASA-Ames Research Center
MS 239-2
Moffett Field, CA 94035

HumRRO/Western Division/Carmel
Office
27857 Berwick Drive
Carmel, CA 93923

Library
Division of Public Documents
Government Printing Office
Washington, DC 20402

JSAS Manuscript Office
1200 Seventeenth Street, NW
Washington, DC 20036

Human Factors Society
Attn: Bulletin Editor
P. O. Box 1369
Santa Monica, CA 90406

OASD (MRA&L)/Training
Room 3B922, Pentagon
Washington, DC 20301

Center for Naval Analyses
Attn: Dr. R. F. Lockman
2000 N. Beauregard Street
Alexandria, VA 22311

Director
Training Analysis & Evaluation Group
Department of the Navy
Orlando, FL 32813

Personnel & Training Research
Programs
Office of Naval Research (Code 458)
Psychological Sciences Division
800 N. Quincy Street
Arlington, VA 22217

National Defense University
Research Directorate
Ft. McNair, DC 20319

Dr. Martin Tolcott
Office of Naval Research
800 N. Quincy Street
Department of the Navy
Arlington, VA 22217

DISTRIBUTION LIST (cont'd)

National Aviation Facilities
Experimental Center
Library
Atlantic City, NJ 08405

Commanding Officer
Air Force Office of Scientific
Research
Technical Library
Washington, DC 20301

Chief of Naval Operations
OP-596
Washington, DC 20350

Office of Deputy Chief of Naval
Operations
Manpower, Personnel and Training
(OP-01)
Washington, DC 20350

Chief of Naval Operations
(OP-115/M. K. Malehorn)
Washington, DC 20350

Naval Research Laboratory
Attn: Library
Washington, DC 20375

Headquarters Marine Corps
Code APC/LTC J. W. Biermas
Washington, DC 20380

Scientific Technical Information
Office
NASA
Washington, DC 20546

Commander
Naval Air Test Center
CT 176
Patuxent River, MD 20670

Technical Library
Naval Training Equipment Center
Orlando, FL 32813

Dr. Donald W. Connolly
Federal Aviation Administration
FAA NAFEC ANA-230 Bldg 3
Atlantic City, NJ 08405

OUSDR&E
Room 30122
Washington, DC 20301

Assistant Secretary of the Navy
Research, Engineering and
Systems
Washington, DC 20350

Chief of Naval Operations
OP-593B
Attn: CDR C. Sammons
Washington, DC 20350

Commander
Naval Air Systems Command
Technical Library AIR-950D
Washington, DC 20361

Commander
Pacific Missile Test Center
Attn: CDR Tom Jones (Code 1226)
Point Mugu, CA 93042

Naval Aerospace Medical Research
Laboratory
Code L-53/CAPT James Goodson
Pensacola, FL 32512

Commander
Naval Air Systems Command
AIR 4135B/LCDR R. Gibson
Washington, DC 20361

DISTRIBUTION LIST (cont'd)

Commanding Officer
Naval Education Training Program
and Development Center
Attn: Technical Library
Pensacola, FL 32509

Commander
Naval Weapons Center
Human Factors Branch
3194/R. A. Erickson
China Lake, CA 93555

Tony Ciavarelli
Dunlap and Associates
920 Kline Street
La Jolla, CA 92037

CAPT D. P. Dunbar
NAVAIRSYSCOM (AIR-06E)
Washington, DC 20361

CDR Mike Long
COMFITAEWINGPAC
NAS Miramar
San Diego, CA 92145

Scientific Advisor
Headquarters U.S. Marine Corps
Washington, DC 20380

Chief of Naval Education and Training
Code 01A
Pensacola, FL 32509

LCDR Cliff Bateman
COMFITWING-ONE
NAS Oceana
Virginia Beach, VA 23460

CDR Dick Jones
COMFITWING-ONE
NAS Oceana
Virginia Beach, VA 23460

Commander
Naval Air Development Center
Attn: Code 6021 (CDR J. Funaro)
Warminster, PA 18974